A Precision Measurement of the Top Quark Mass with the DØ Detector

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The standard model of particle physics is based on the gauge group SU(3) $\times$ SU(2) $\times$ SU(1) which describes the the interactions of the fundamental particles of nature. The particles which have been observed can be categorized into three major groups: quarks, leptons, and gauge bosons. The quarks and leptons form a group of particles called the fermions and are grouped in three generations of two particles each. All of the "normal" matter (protons, neutrons, and electrons) are from the first generation. The top quark is in the third generation and can be produced only in high-energy interactions. It is the most massive fundamental particle observed in nature having a mass which is approximately the same as an entire gold nucleus. A precise measurement of the top quark mass is quite useful in interpreting other measurements because many electroweak observables are sensitive to radiative corrections involving the top quark. Most importantly, a precision measurement of of the top quark mass together with a measurement of the W boson Mass, will help improve the indrect constraints on the Higgs boson mass.

Currently, the only laboratory that is capable of high enough energy interactions to produce the top quark is the Tevatron accelerator located in Batavia Illinois. The topic of my thesis work is a measurement of the top quark mass at the DØ experiment. The DØ detector is a large multi-purpose collider particle detectors at the Tevatron. The Tevatron collides protons and anti-protons ($p\overline{p}$) at the worlds highest center of mass energy of 1.96 TeV. The top quark is pair-produced by QCD processes involving quark/anti-quark annihilation or gluon fusion. The standard model predicts that the top quark will decay into a bottom quark and a W boson with a branching ratio which is almost unity. The W boson can decay into either leptons or hadrons while the bottom quark hadronizes into a high energy jet of hadronic particles. The final states of pair produced top quarks can be classified according to how the W boson decays. In the "lepton+jets" events, which constitute approximately 30% of the events, there are four hadronic jets (two from the bottom quarks and two from the decay of the W boson) a charged lepton and a neutrino. Since the tau lepton is harder to identify experimentally we do not classify it as part of the lepton + jets channel. All of these objects can be identified by the detector, except the neutrino because it interacts so weakly with matter. Since the quarks and the anti-quarks within the proton and anti-proton are colliding we do not know what the resultant logitudinal momentum is for the quark anti-quark collisions, but we expect that in the transverse plane they will have essentially zero total momentum. Hence, in events with high energy neutrinos we expect to find signficant "missing" transverse momentum which can be identfied as the neutrino's transverse momentum.

There are two major sources of background to the lepton + jets channel. First there are events where a W boson decays leptonically where there are multiple jets produced from initial state gluon radiation from a quark in the hard scattering or underlying event (from the nuclear breakup of the initial proton and anti-proton). This constitutes the main physics background to this channel. The main instrumental background are multi-jet events where the event is significantly mis-reconstructed. Although the probability of this is very small for any particular event, the cross-section for multi-jet events is some six orders of magnitude larger. There are several methods that are used to reduce the background and obtain a cleaner sample of top quark events. One of the most important of these is the identification of jets which originate from bottom quarks. Since every top quark event is expect to have a bottom and anti-bottom quark while the background is almost entirely composed of jets from light quarks being able to identify these jets is crucial to the measurement. Since the bottom quark and its antiparticle have a lifetime of about 1.6 ps, for a typical momentum of approximately 40 $\frac{GeV}{c}$ the decay length is about 3 mm. Tracks from the decay of a long-lived b-hadron will point back to the point where the b-hadron decayed and not where hard scattering took place. By identifying these "secondary" vertices and associating them with the jets of hadrons we can both reduce the background significantly and increase our knowledge of the event and extract more precise information.

The goal of my thesis is to extract the top quark mass from the data collected with the DØ detector. The final state objects are four hadronic jets, a charged lepton, and the "missing" transverse momentum of the neutrino. By assuming that two of these jets and the lepton and neutrino came from the decay of a W boson, one has two constraints of the invariant mass of these objects. As well, the top and anti-top quark must have equal masses which gives a third constraint. Hence, we have three constraints and one unknown (the momentum of the neutrino in the direction of the beam). A twice-constrained kinematic fit to the top quark hypothesis is used to extract the fit mass for the event. By comparing the fit mass distribution to a detailed Monte Carlo simulation of top quark events a likelihood fit is used to extract the most likely value of the top quark mass from the data.

1 Thesis Outline

1. **Introduction**
   - (a) The Standard Model
   - (b) Review of the Top Quark (experimental and theoretical)
   - (c) Testing the Standard Model with the Top Quark
   - (d) Testing other models of Electroweak Symmetry Breaking with the Top Quark
2. **Experimental Apparatus**
   - (a) Tevatron Accelerator
   - (b) DØ detector
     - i. Silicon Detector
     - ii. Central Tracking Detector
     - iii. Calorimeter
     - iv. Muon System
     - v. Trigger and Data Acquisition
     - vi. The Silicon Track Trigger
3. **Object Identification**

    (a) Reconstruction and particle ID
        i. Electron
        ii. Muon
        iii. Jets and Missing Transverse Momentum
    (b) Secondary Vertex Identification

4. **Event Selection**
    (a) Signal Simulation
    (b) Background Estimation
    (c) Bottom Quark Identification
    (d) Topological Likelihood

5. **Methods for Top Quark Mass Measurements**
    (a) Kinematic Fitting
    (b) Template Likelihood Fitting
    (c) Ensemble Testing

6. **Results of Data Analysis**
    (a) Results on data
    (b) Systematic Error Estimation
    (c) Cross Checks

7. **Summary and Outlook**